Lessons Learned from Radiation-induced Effects on Solid State Recorders and Memories

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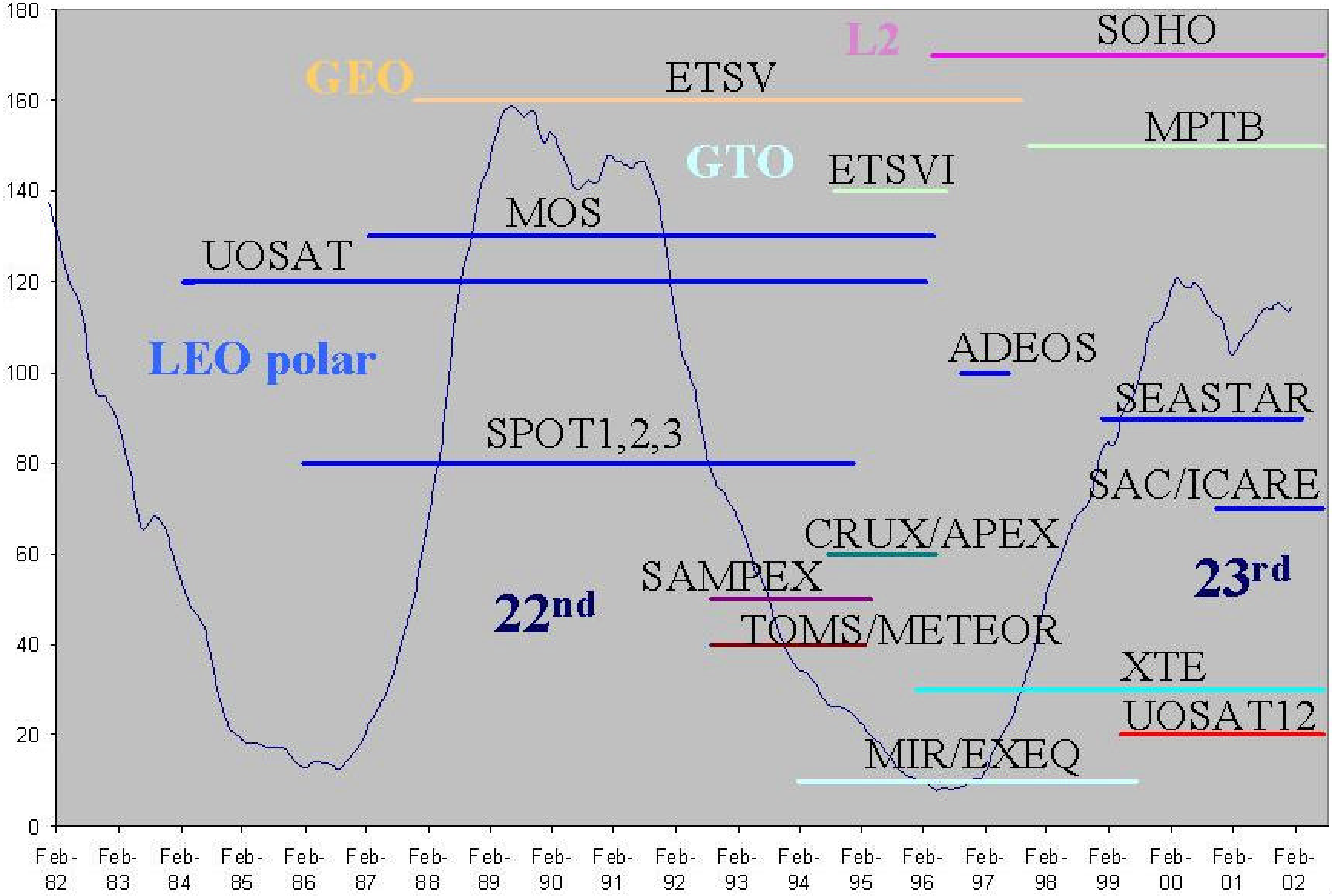
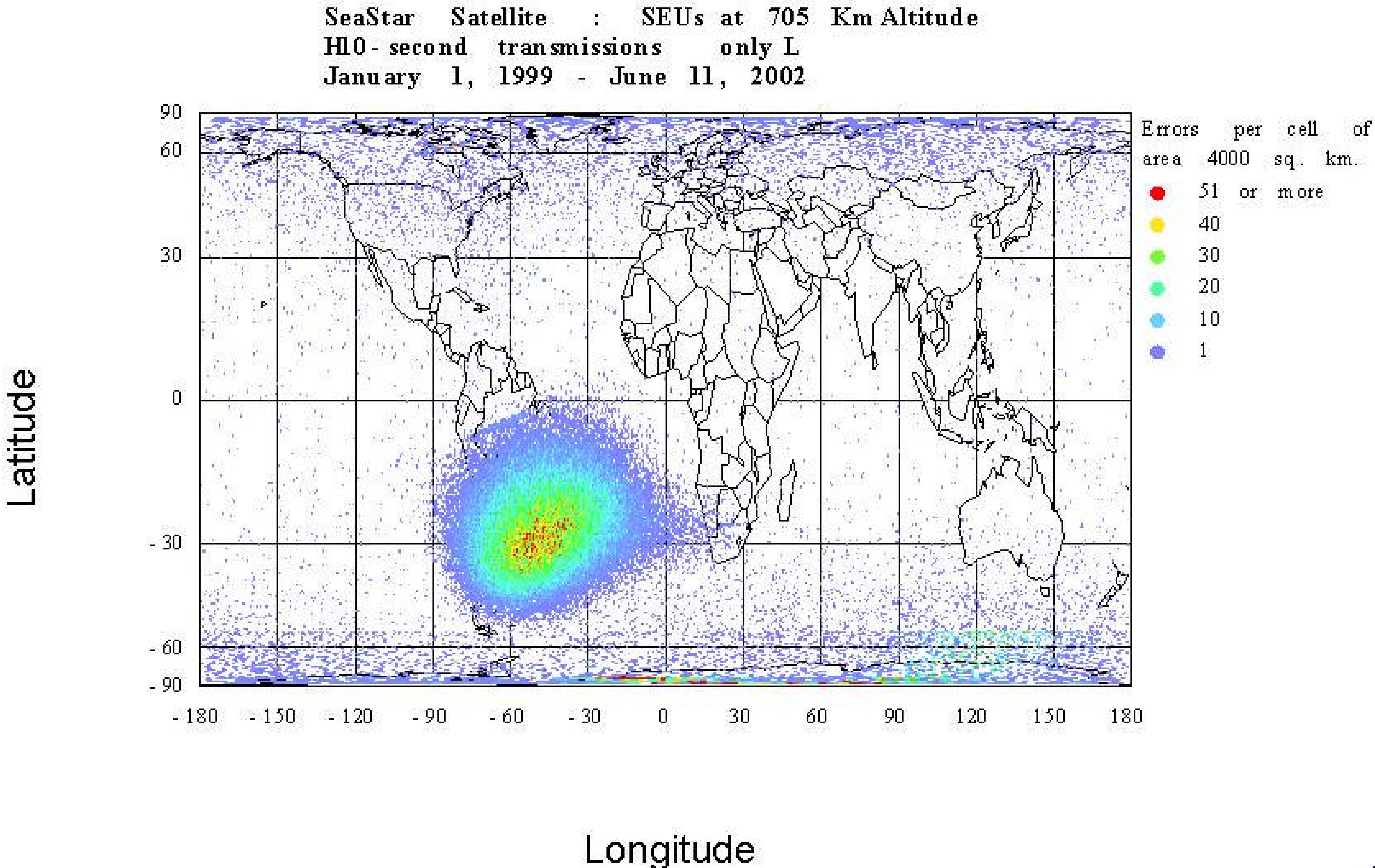
Outline

- Introduction
- Examples:SEASTAR,APEX/CRUX
- Accuracy of upset rate calculations
- Efficiency of SEU mitigation schemes
- Conclusion

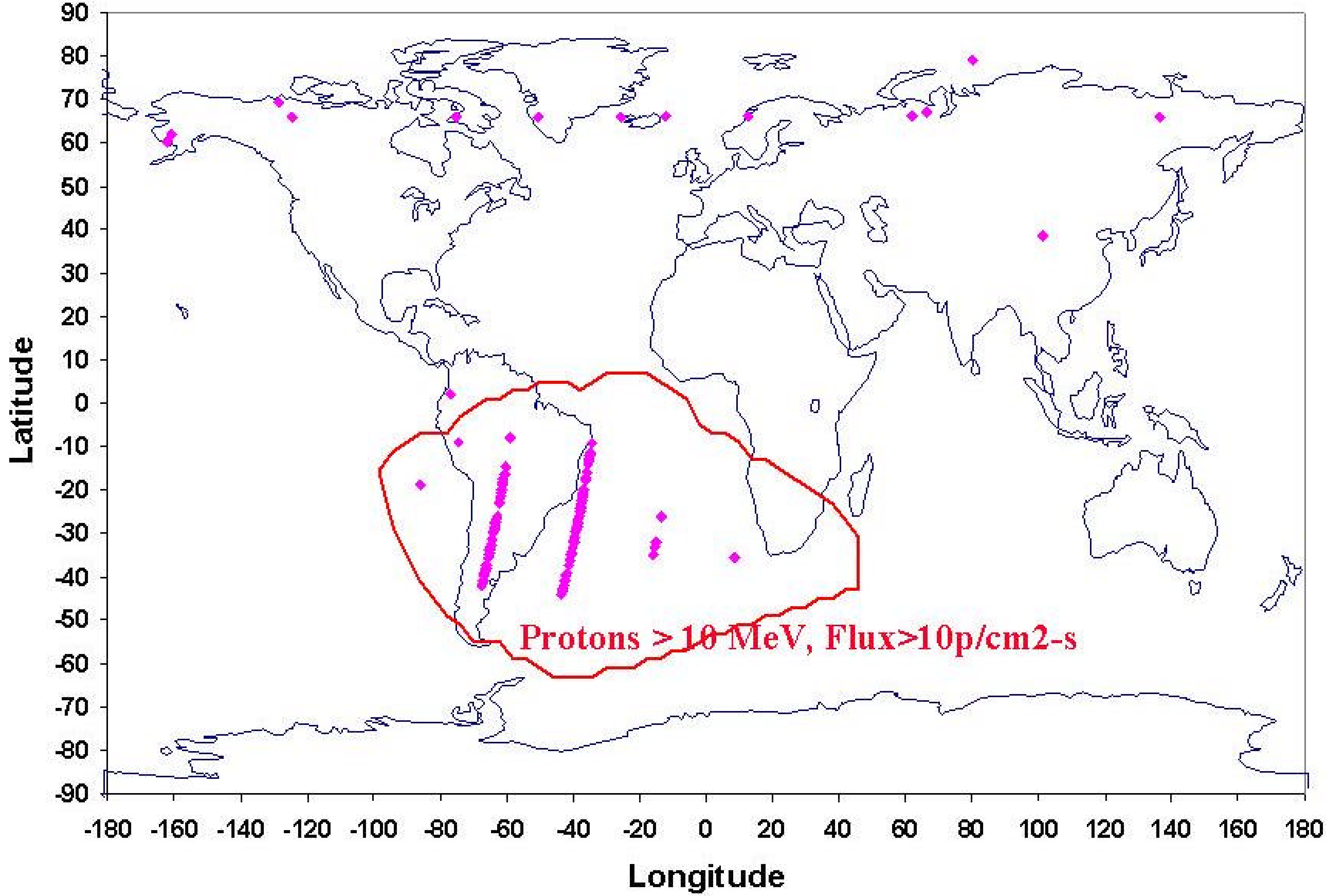
Introduction



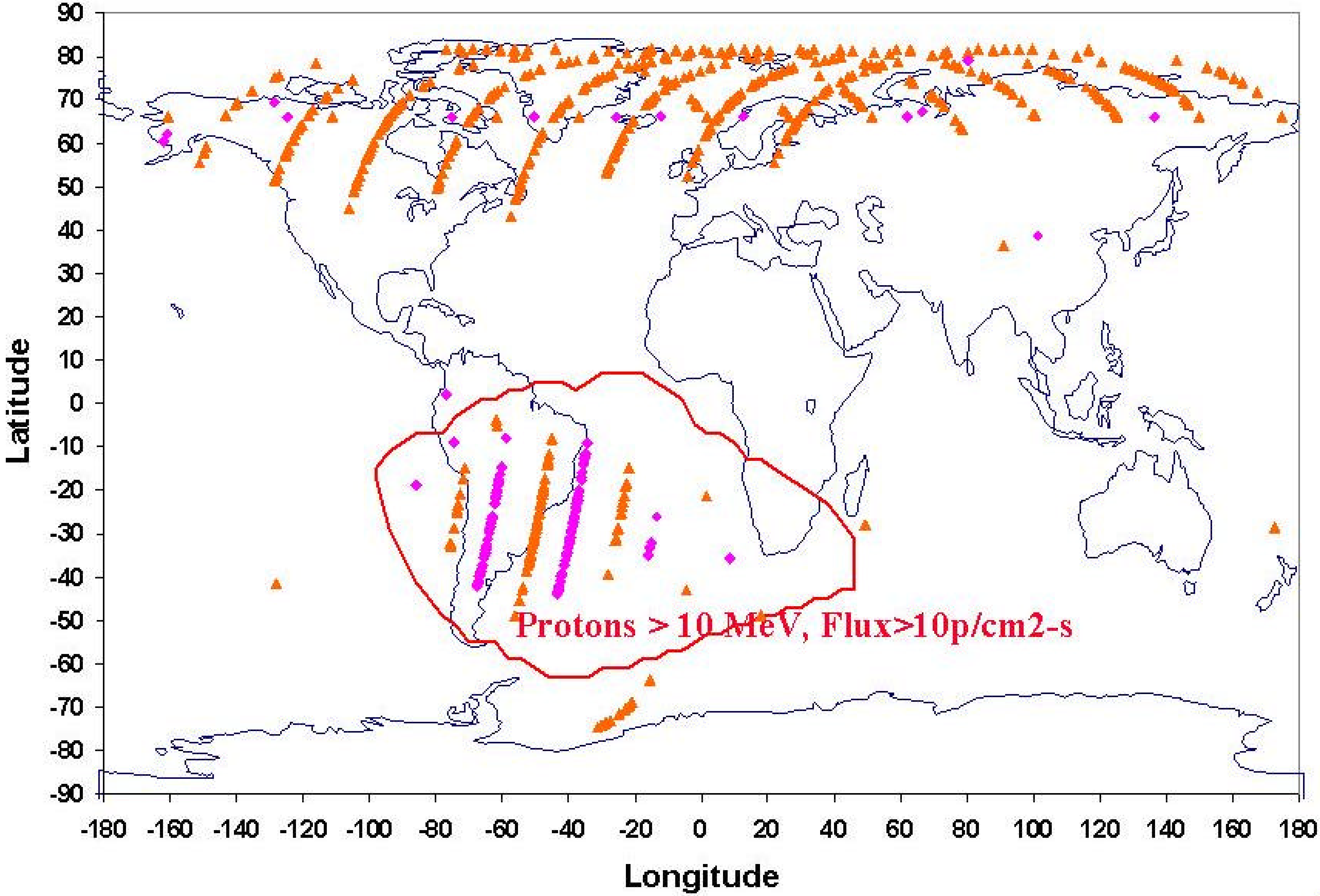
Flight Data Examples, Seastar-Geographic Plot of Single Hits



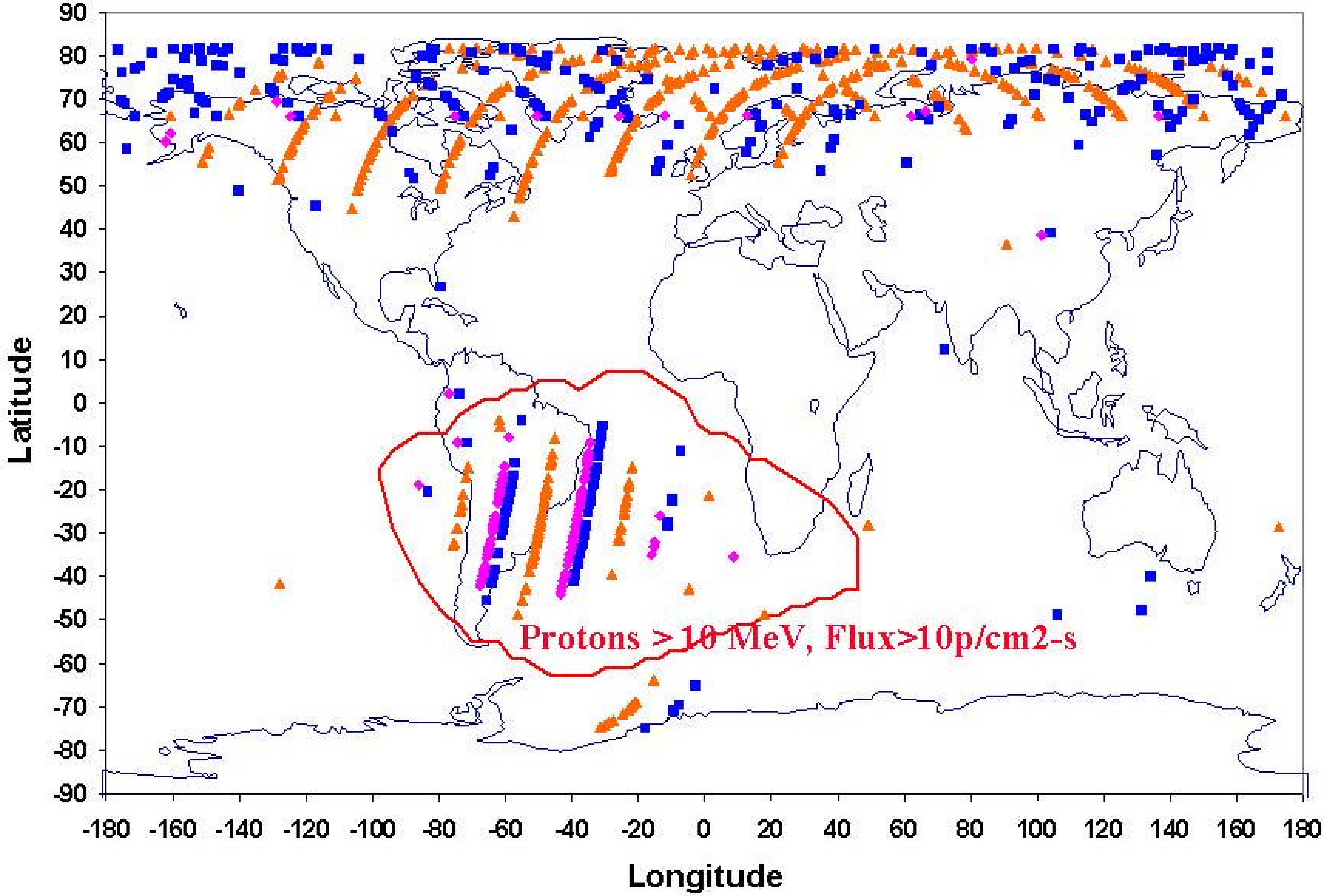
Typical day 7/13/200: ~ 80% of SEU occur in SAA



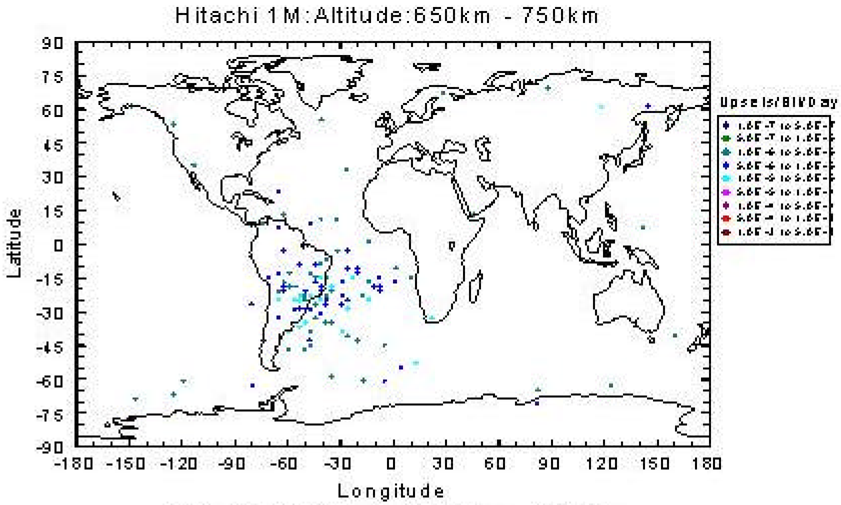
Solar Event 7/14/2000

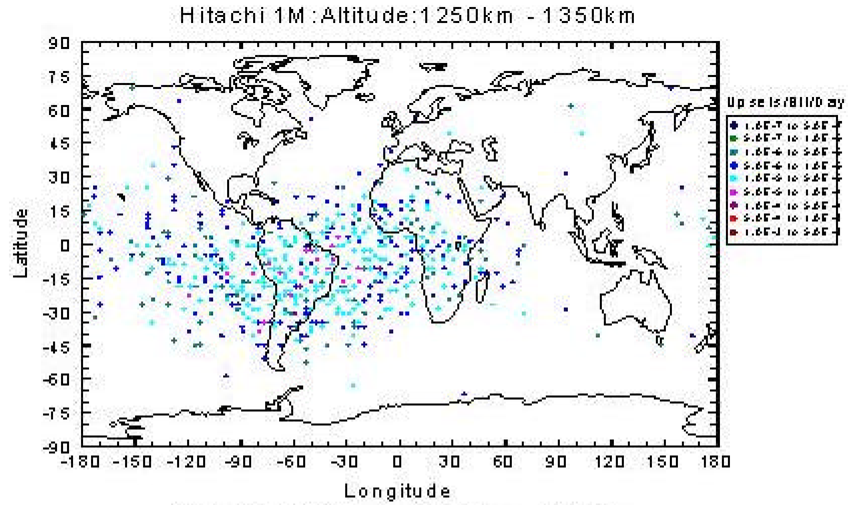


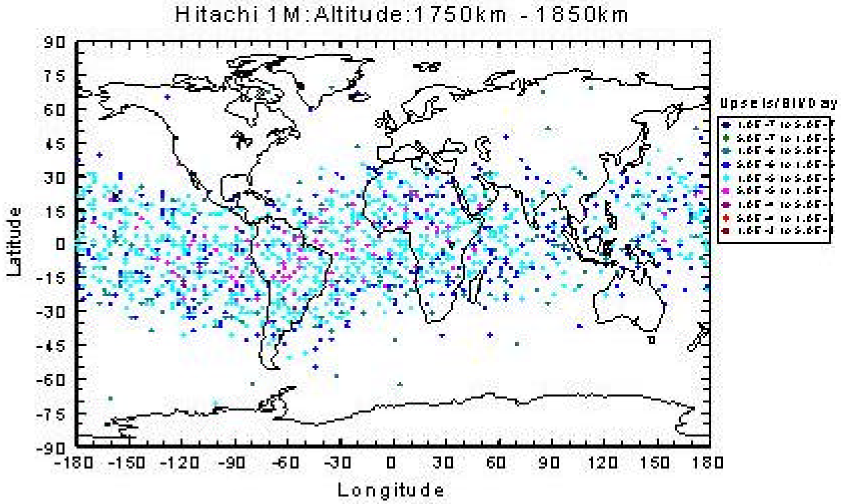
Solar Event: 7/14-15/2000

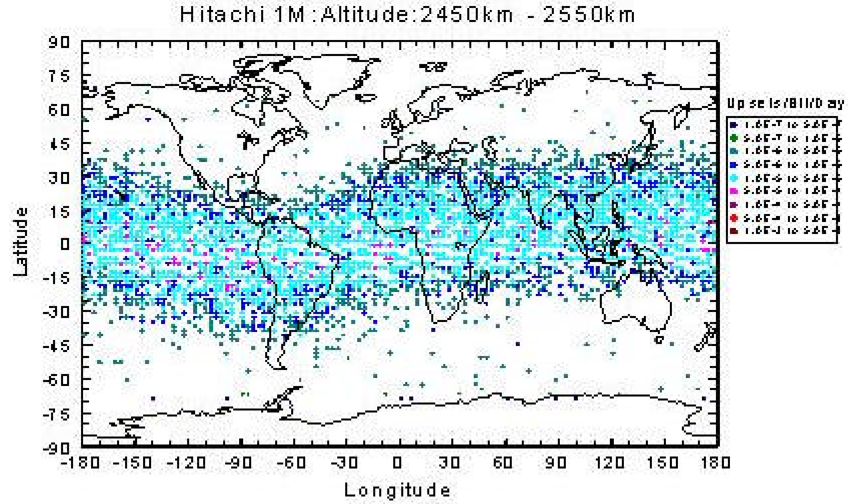


SRAMs Upset Rates on CRUX/APEX

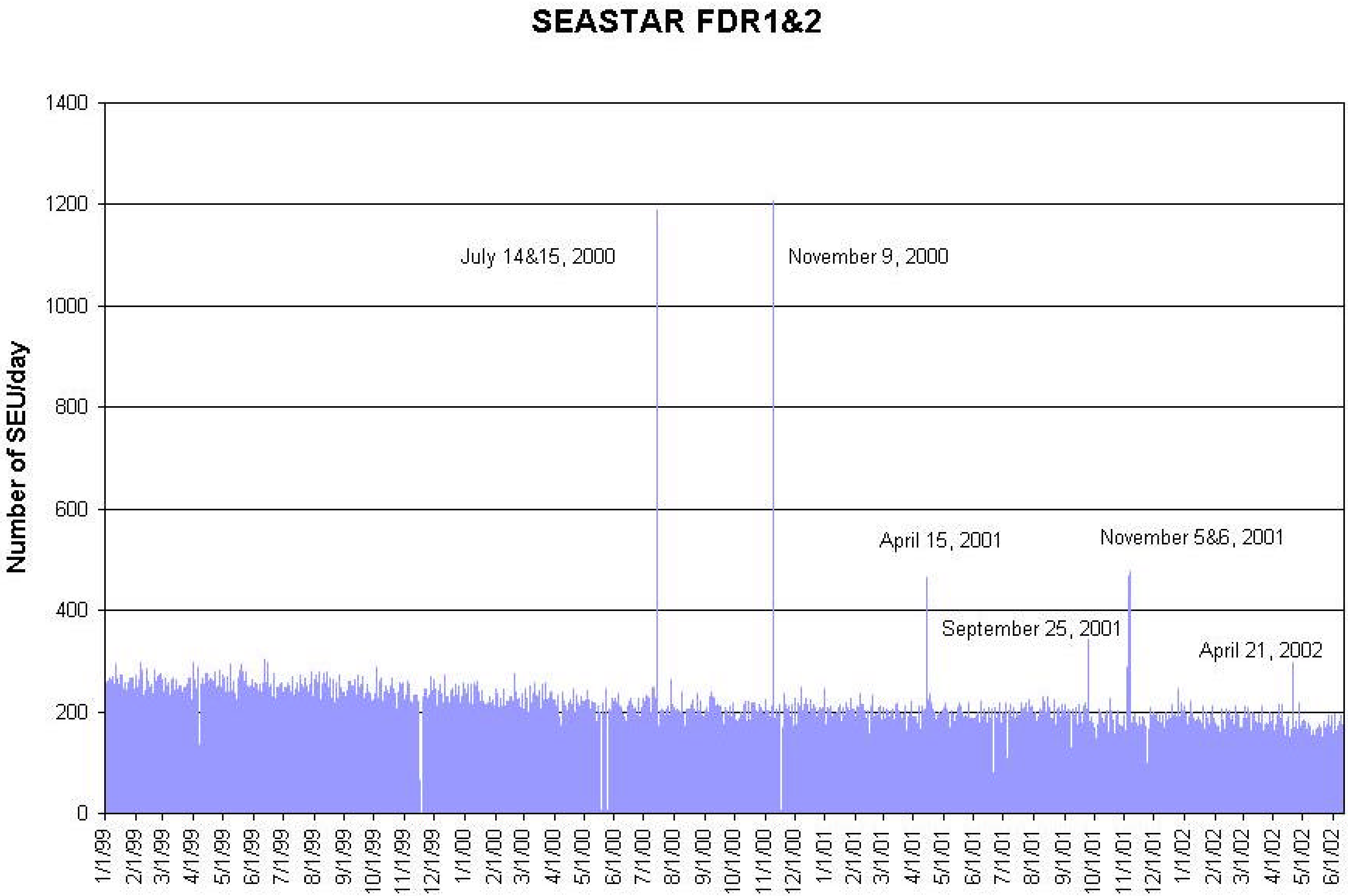




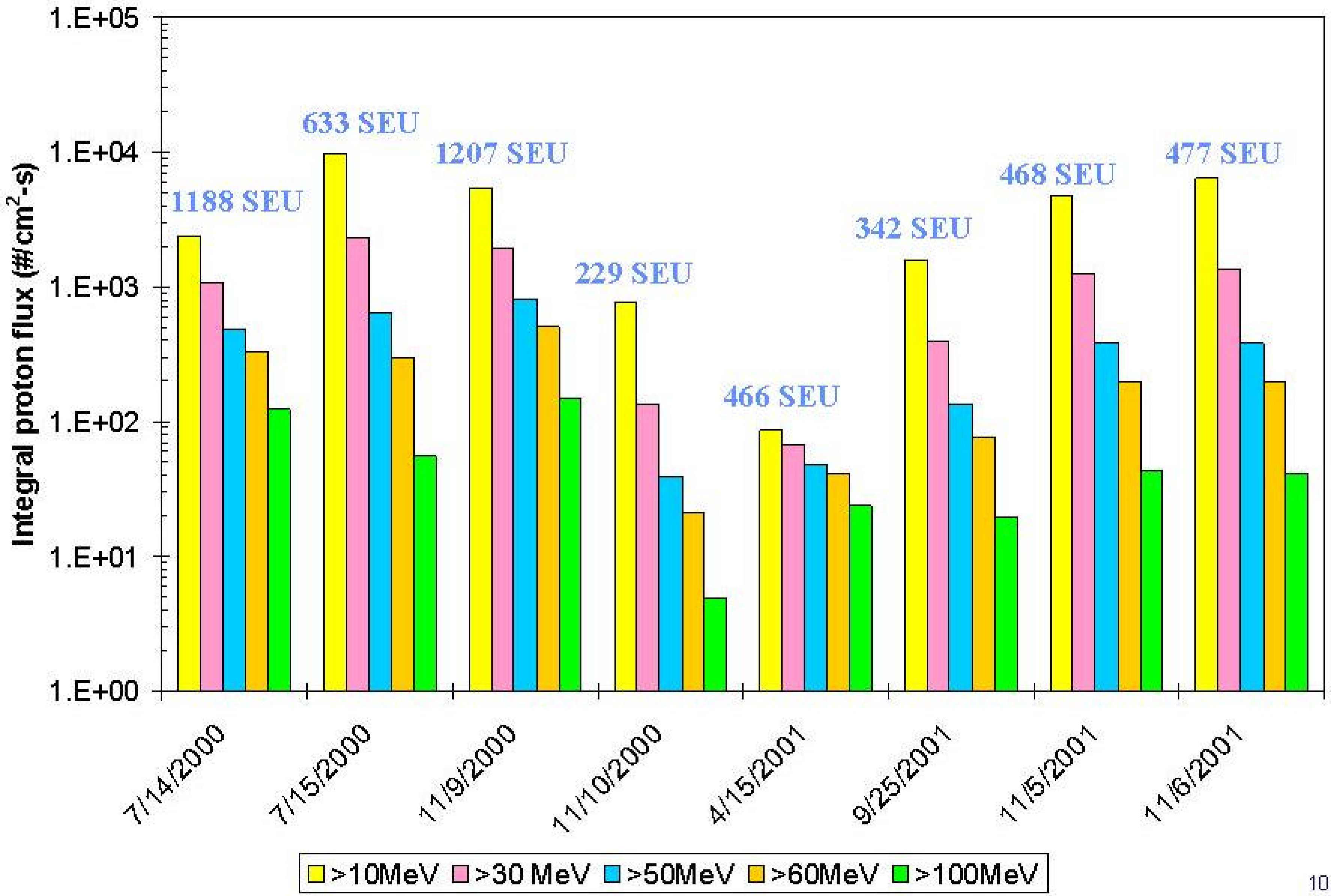




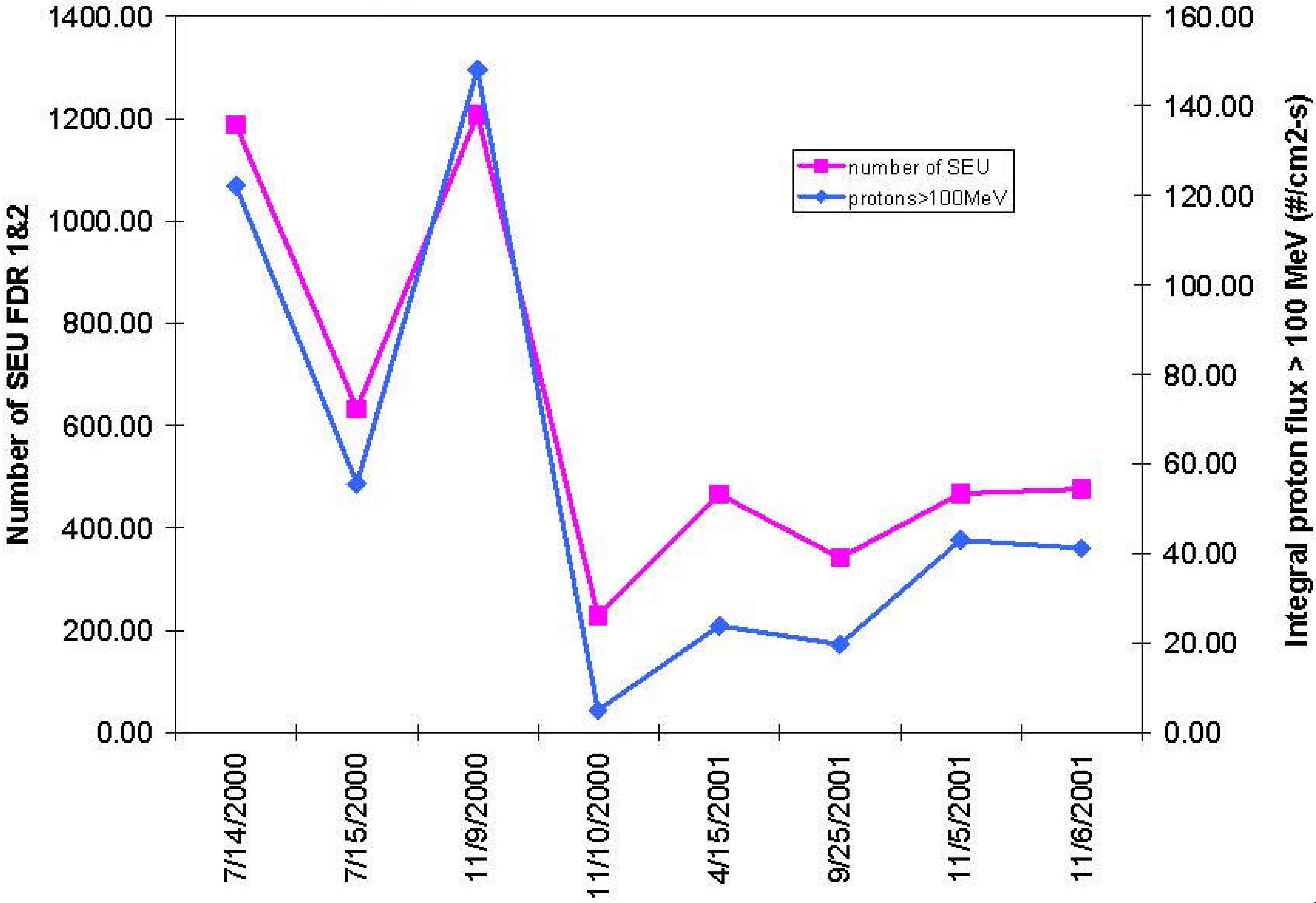
Evolution of SEU rate versus time



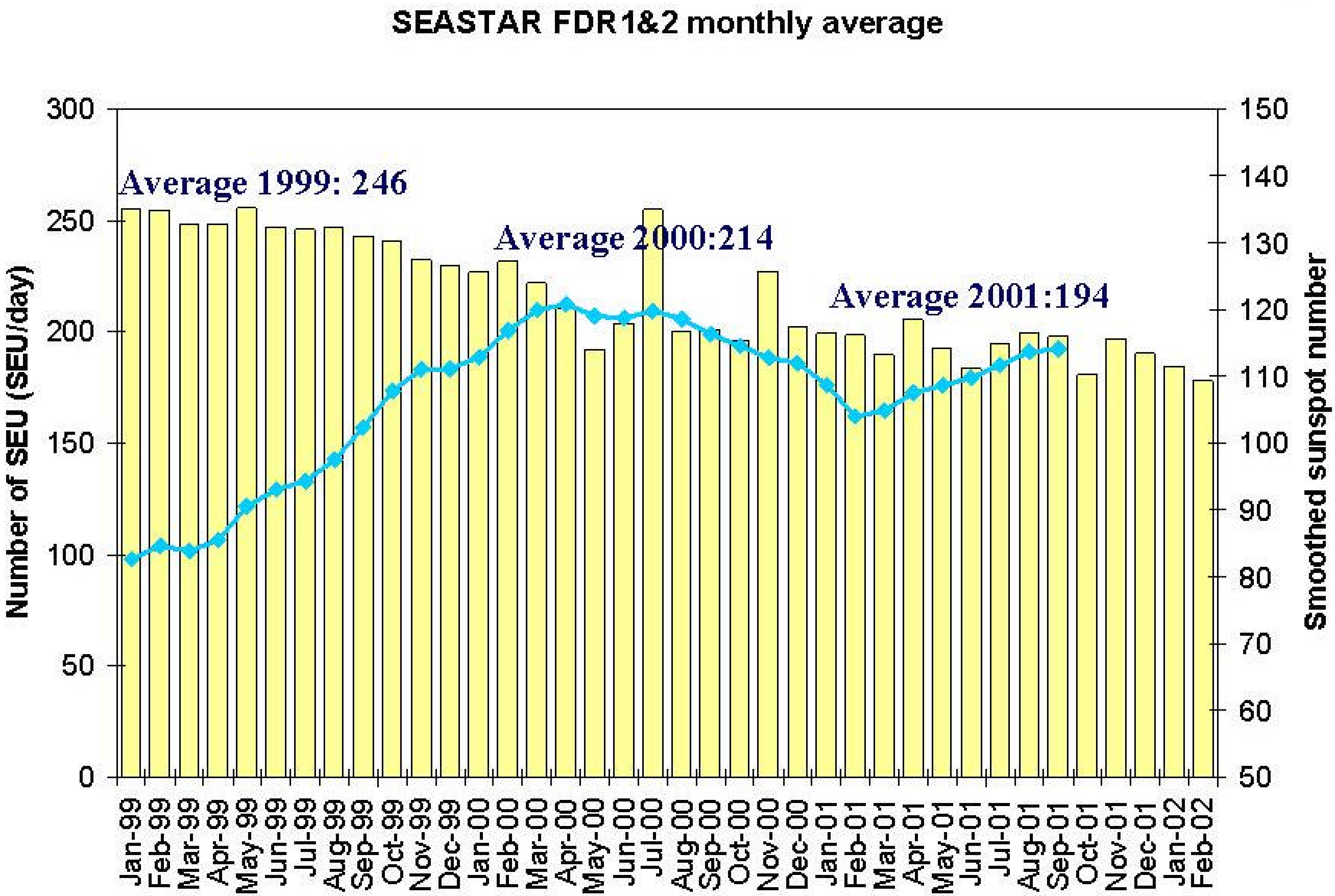
Proton composition of main solar events



Solar proton >100 MeV flux compared to SEU number



Modulation of the SEU rate with solar activity



Predictions of the upset rates

- Proton rates are generally underestimated and heavy ion rates overestimated, but generally an overall acceptable agreement is observed (within an order of magnitude) if:
  - Adequate environments models are used (CREME96) with the adequate solar modulation.
  - Heavy ion and proton data has been taken
- But discrepancies have been observed. They are due to:
  - SPE Environment models
  - Ground testing sample size
  - Assumptions on sensitive volume geometry for heavy ion rates

SPE environment models

- SOHO SSR (DRAM 4M)
  - Predicted rate orders of magnitude higher than the observed rate during July 14 event (During quiet period agreement within a factor 2 with CREME96 model). Possible causes:
    - Shielding effect (assumed 1g/cm^2 of shielding)
    - CREME96 SPE models, (especially the ion component).
- MPTB DRAM (DRAM 16M) experiment
  - Predicted rates orders of magnitude higher than the observed rates during July 14 event (During quiet period, agreement within a factor 10). The cause has been attributed to the CREME96 model, because a good agreement was found with the actual measured spectra (CREDO3 instrument).

Ground Testing Sample Size

- APEX CRUX (SRAM256K & 1M experiment), surprising results obtained because of large part to part variation (up to a factor 10)
    - Large part to part variation confirmed by ground testing
    - Variation of +/30% can be explained by the shielding
- HST SSR (12 Gbit made with 1440 DRAM 16M) anomaly was not detected by initial ground testing
  - Anomaly due to a SEFI, low device event sensitivity (~6E-13 cm^2/die)
  - Sensitivity confirmed during ground testing of 100 parts
- Large part to part dispersion also observed on UOSAT and EXEQ experiments.

Assumptions on Sensitive Volume Geometry

- EXEQ experiments
  - A conservative assumption of the sensitive volume thickness (2 μm) leads to a factor 45 overestimation of the flight rates on a 16M DRAM.
  - A probing of the sensitive volume with low energy ions, showed a sensitive volume thickness of about 7 μm.
  - With this value the ratio calculated rate to flight rate is reduced to a factor 4.

Efficiency of SEU mitigation Schemes

- Generally EDAC techniques in association with a continuous scrubbing to "wash" the SEU have been successful.
  - Hamming:
    - SSR: SAMPEX (SRAM256K), TOMS (SRAM 256K), SEASTAR (DRAM4M),XTE(SRAM1M), UOSAT, SOHO(DRAM16M)
    - OBC memory: UOSAT (SRAM)
  - Reed Solomon:
    - SSR: UOSAT(SRAM256K&1M), UOSAT12(SRAM4M), HST (DRAM16M)
  - TMR
    - OBC memory: UOSAT12 (SRAM4M)
      - 200% overhead of memory size
      - No significant advantage compared to a modified Hamming code capable of correcting two errors per word.

Multiple Bit Upset (MBU)

- A good SEU mitigation design needs a good understanding and ground testing of the MBU.
  - MBU mechanisms.
    - Charge diffusion away from an ion .
      - several neighboring cells are affected.
      - A different number of cells is affected depending on the ion LET and ion angle of incidence.
    - ion strike in the control circuitry.
      - Block error, row-column error .
    - Ion track intersecting a number of memory cells.
      - Difficult to test at ground level.

MBU in space

- MBU have been observed in flight in all experiments
  - Most MBU occur in high latitude regions (more MBU caused by heavy ions than protons).
  - Blocks errors and multiple errors induced by a ion at grazing incidence have been identified on MPTB/DRAM experiment.
  - Significant rate (>10% of total upset rate) observed on more modern memories (DRAM>16M, SRAM 4M), SAC-ICARE experiment.
  - Single word multiple bit upset (SMU) have been reported on SAC-ICARE and UOSAT12 experiments.
  - Unexpected number of uncorrectable errors on CASSINI SSR.
    - The cause is a bad design: a data word is made with several memory word that have neighboring cells.
    - The uncorrectable error rate is still acceptable for the mission.

Scrubbing Rates

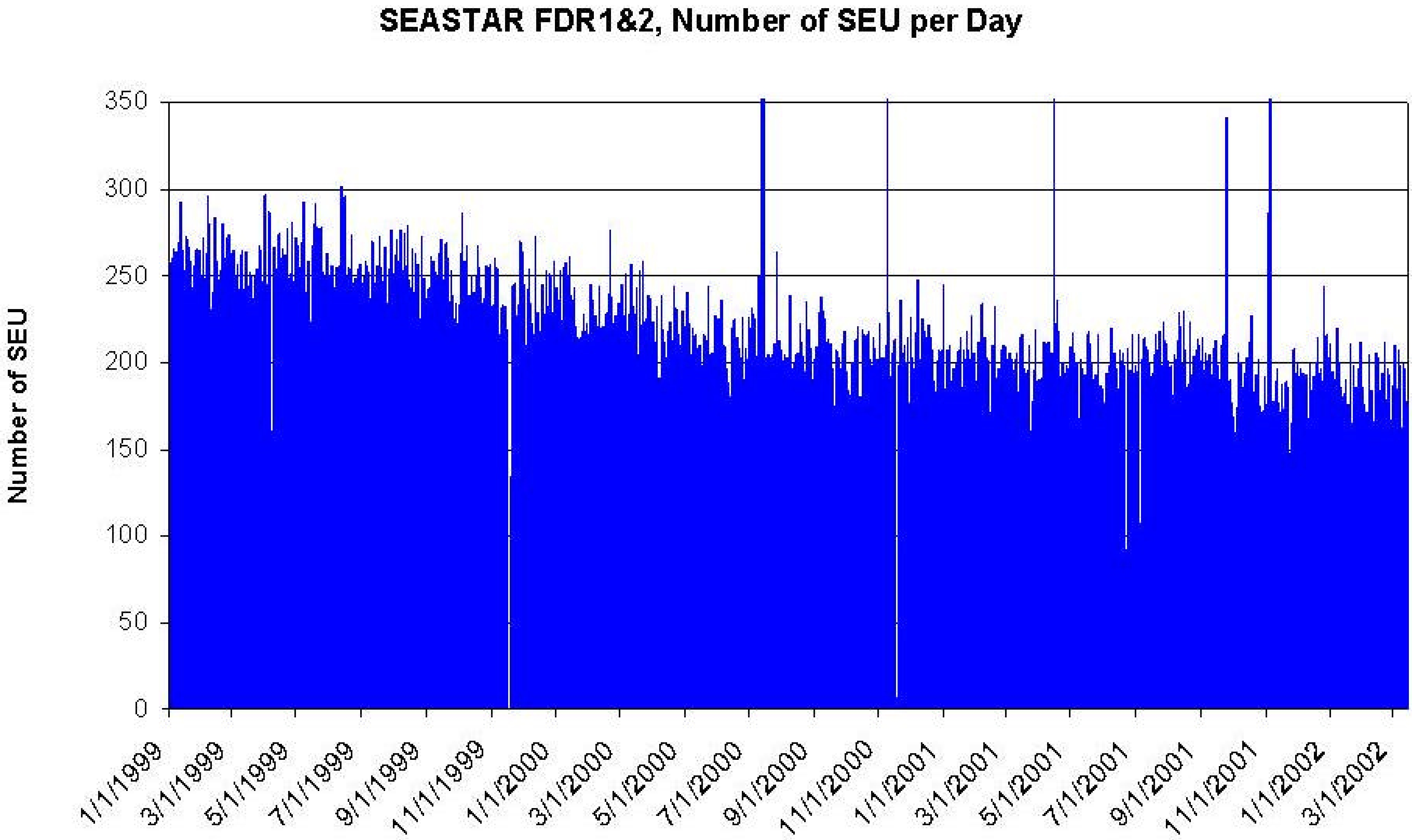
- Traditionally scrubbing rates are calculated on the basis of daily averaged SEU rates.
- Flight data has shown that SEU occurs in burst (very high upset rate during a short period of time).
  - when the spacecraft goes trough the radiation belts.
  - During a SPE.
- Scrubbing rates need to be calculated for a peak upset rates.

Conclusion

- The use of high density commercial memories in space applications has been a success.
- Flight experiments have been very useful to understand the behavior of parts and validate the SEE mitigation schemes.
  - The experiments that include a radiation monitor allow a better understanding of the results (MPTB, SAC-ICARE).
  - It is also important to have an accurate information about the shielding thickness (MPTB, CRUX APEX).
- Modern memories are more and more complex (ie SDRAMs)
  - Significant sensitivity to SMU.
  - Significant SEFI sensitivity.
  - experiments are needed on these devices.

Back-up

Modulation of the SEU rate with solar activity



SeaStar Mission

Altitude:

705 km - 705km

Inclination:

98.2°

Dates: September 1997 - Present

- Data from 1/1/1999 to 3/12/2002 has been analyzed for this study

Technology:

- FDR1&2 - Seakr Solid State Recorders (SSR) w/ 64MB of Memory
  – EDAC (16,22) Modified Hamming Code - single bit correct, double bit detect
  – Telemetry gathered at 10 second intervals
  – Watchdog timer w/ soft reset - 1 second timeout
- DRAM - Hitachi MDM1400G-120, 4megabit x 1bit
  – 220 DRAMs per FDR
  – designed in 1994; now obsolete and hard to find

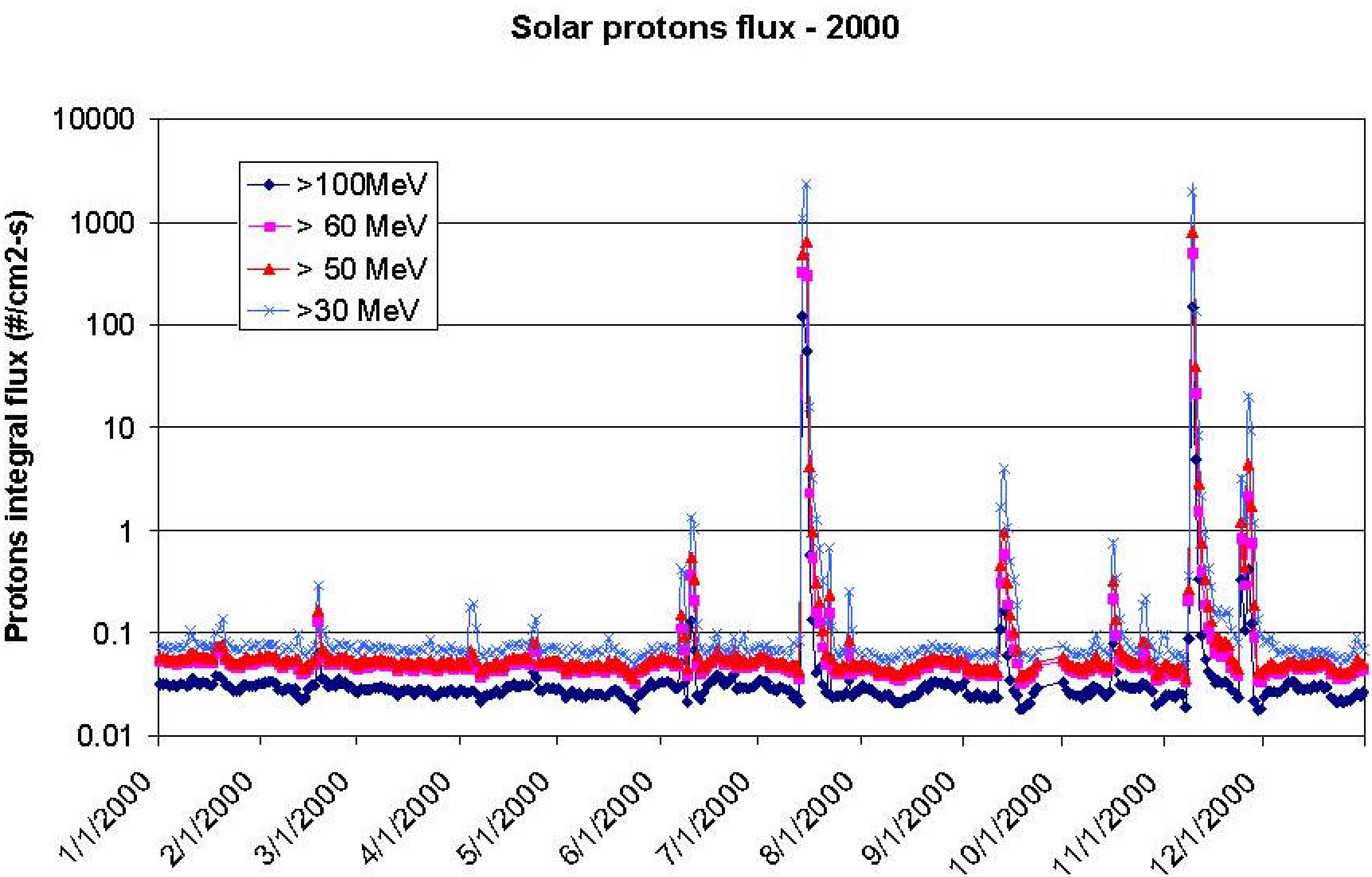
Introduction

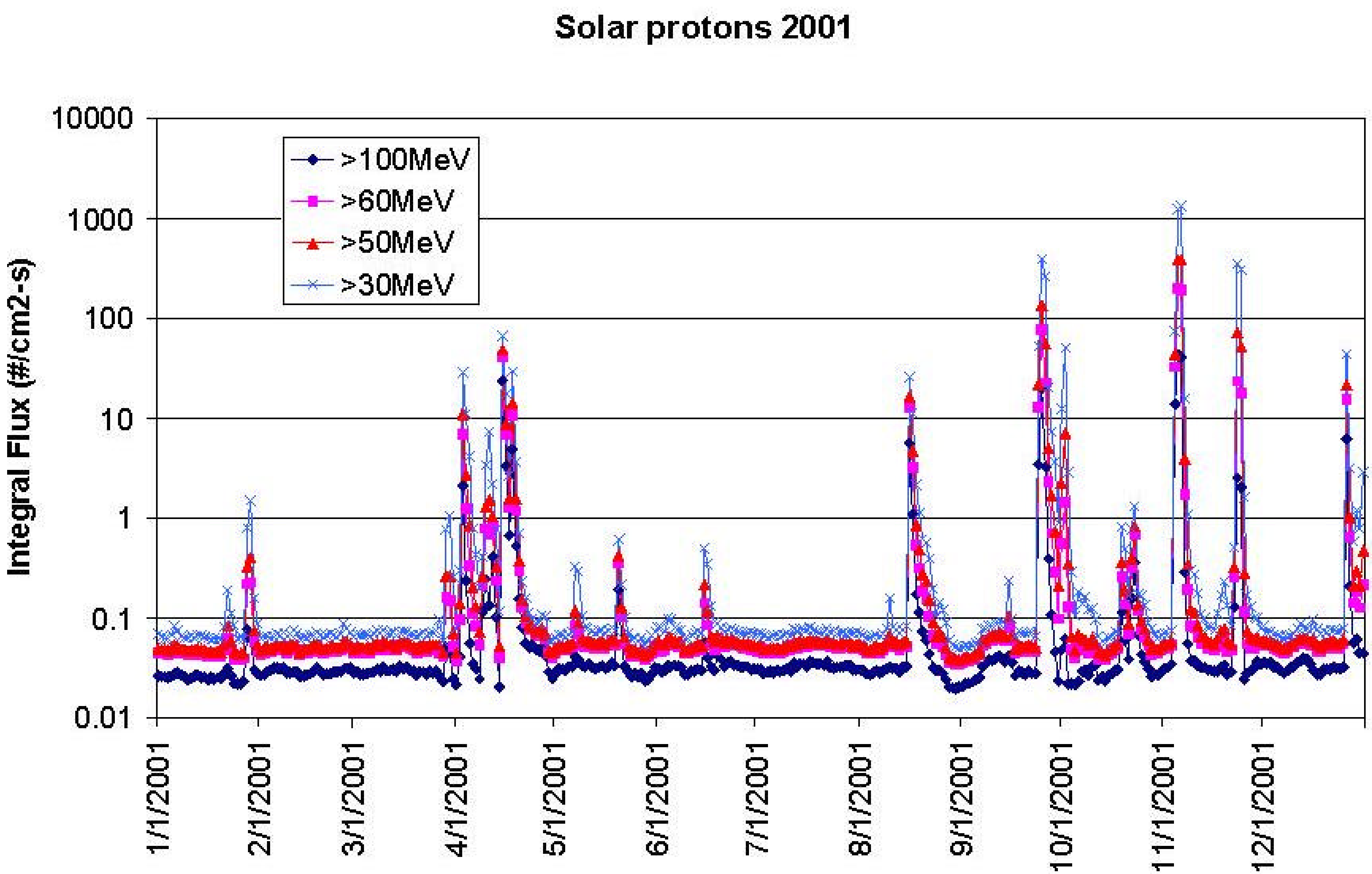
- SEASTAR in flight SEU performance were presented in SEE2000 symposium. We present an update that shows the effect of the solar activity and Solar Particle Events (SPE).
- Then we present the the anomaly on the Microwave Anisotropy Probe (MAP) that has been probably caused by solar heavy ions.

- SRAM
  - 0.5K
  - 1K
  - 4K
  - 64K
  - 256K
  - 1M
  - 4M
- DRAM
  - 4M
  - 16M
  - 64M

Conclusion SEASTAR

- The data collected shows a significant sensitivity to solar protons.
- But only high energy protons (>100 MeV). This suggests a significant amount of shielding.
- The data also shows the fluctuation of the SEU numbers (and therefore the trapped proton fluxes) with the solar activity.


Solar protons flux - 2000
Protons integral flux (#/cm2-s)
10000
1000
100
10
1
0.1
0.01
>100MeV
> 60 MeV
> 50 MeV
>30 MeV
1/1/2000
2/1/2000
3/1/2000
4/1/2000
5/1/2000
6/1/2000
7/1/2000
8/1/2000
9/1/2000
10/1/2000
11/1/2000
12/1/2000


Solar protons 2001
Integral Flux (#/cm2-s)
10000
1000
100
10
1
0.1
0.01
>100MeV
>60MeV
>50MeV
>30MeV
1/1/2001
2/1/2001
3/1/2001
4/1/2001
5/1/2001
6/1/2001
7/1/2001
8/1/2001
9/1/2001
10/1/2001
11/1/2001
12/1/2001